MURI-ASAP

Optimal Asset Distribution for Environmental Assessment and Forecasting Based on Observations, Adaptive Sampling, and Numerical Prediction

Dr. Pierre F.J. Lermusiaux – co-PI
Department of Mechanical Engineering, Center for Ocean Science and Engineering,
Massachusetts Institute of Technology; 5-207B; 77 Mass. Avenue; Cambridge, MA 02139-4307
phone: (617) 324-5172 fax: (617) 324-3451 email: pierrel@mit.edu

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LONG-TERM GOALS and OBJECTIVES

1. *Carry out cooperative real-time (sub)-mesoscale data-driven predictions with adaptive sampling and research and evaluate skill measures*
2. *Advance scientific understanding of 3D upwelling/relaxation dynamics and carry out budget analyses as possible (multi-balances, sensitivity studies, parameterizations, predictability)*
3. *Determine details of three metrics for adaptive sampling (coverage, dynamics, uncertainties) and develop schemes and exercise software for their integrated use*

APPROACH

1. Further modeling system improvements and skill metrics
   a. Re-analyses and Multi-model comparison and combination
2. Ocean Dynamics
   a. Ocean Flux and Term Balances: AN Budgets, Tidal effects, Eddying off AN shelf, Undercurrent and CC dynamics/interactions, Coastal trapped waves, etc
   b. Study impact of larger-scale effects shown today on AN shelf
3. Data Assimilation (DA), Uncertainty and Predictive capability
4. Energy and Vorticity Analysis (EVA), Scale estimation and LCS for dynamics, sampling and DA

WORK COMPLETED

Real-time Modeling, Dynamics and Reanalysis: Using an improved estimate of the barotropic tides (made possible by improved open boundary conditions to the barotropic tidal model), a sensitivity study focused on the bottom friction parameterization was carried out for the MB06 region. To do so, we used our new two-way nested schemes (see below). From this set of nested simulations, new nested reanalysis fields were selected based on data-forecast misfits. Using this selected reanalysis, a study of the thermal fluxes during upwelling periods was initiated. A box was defined around point Ano Nuevo, contained within the 500m resolution nested sub-domain and containing the region of upwelling. The time rate of change of temperature in the volume is expressed as the advective flux through the lateral boundaries plus the diffusive flux through the ocean surface. Finally, a manuscript on the real-time forecasting and reanalysis for AOSN-II has been published (Haley et al, 2009).

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Ocean Flux and Term Balances: Work is ongoing into the investigation of the volume and term balances associated with the varying types of upwelling events of the extended Monterey Bay region. Volume and term balances for the individual events are being decomposed into mean and variable contributions so that the events can be inter-compared. The effects of differing atmospheric forcing contributions (wind, surface heating, evaporation-precipitation) are under study. Tidal effects are being examined utilizing pairs of simulations in which tides are either included or not. We showed that the higher-frequency flux variability was due to tidal and inertial effects but not due to data assimilation cycles.

New Nested Schemes for Free-Surface Primitive Equation Modeling: In a parallel development to the flux analyses, the nesting algorithm was reexamined to eliminate an observed drift between the barotropic velocities computed in the different domains of 2-way coupled nested simulations. In this work, one overarching constraint was the maintenance of the vertically integrated continuity equation. For the free surface primitive equation model this stipulates that changes made by the nesting algorithm do not unbalance the Helmholtz equation used to construct the surface elevation nor the equation used to construct the final estimate of the barotropic velocity from the surface elevation. In the original algorithm, the vertically integrated right-hand side of the momentum equation was averaged in the fine domain and used to replace corresponding values in the coarse domain. Then the surface elevation and barotropic velocities were computed in the coarse domain and boundary values interpolated for the small domain. For the new algorithm, several modifications to the above algorithm were found that also maintained the vertically integrated conservation of mass. First, instead of averaging the vertically integrated right-hand side of the momentum, an intermediate estimate of the barotropic velocity is averaged on the fine grid and used to replace corresponding values on the coarse grid. Second, the surface elevation in the fine grid is averaged and used to replace the corresponding values in the coarse grid (lagged 1 time step behind the transfer of the other quantities). Finally the barotropic velocity in the coarse domain at this lagged time step is recomputed to be consistent with the new surface elevation. To test these algorithmic changes a simplified test case was designed to isolate the nesting algorithm from effects of coastlines, topography and external forcing. A flat-bottomed (5000m), East-West periodic channel was defined (1000km x 1000km) with straight, solid North/South walls. (Figure 1). In the center of this channel was located an open nested sub-domain (333km x 333km). The initial conditions were that of a periodic sinusoidal jet with smoothed Gulf Stream vertical profile. Outside of the jet the initial mass field was flat and the velocities quiescent.

Forecasting Skill: In (Heubel, 2008), skill metrics have been utilized to evaluate the performance of various mixing parameterizations and tidal model setups for MB06.

Tidal modeling: A mixed open boundary condition scheme (Logutov and Lermusiaux, 2008; Logutov, 2008) was applied to improve the simulation of sub-inertial diurnal tidal constituents in the ASAP domain. The effects of the OBC formulation, frictional and dissipative effects were studied. The ADCP data acquired from Steve Ramp were utilized for model-data comparisons. The barotropic model outputs were compared against the ADCP data at two mooring sites off the coast of Ana Nuevo.

RESULTS

Real-time Modeling, Dynamics and Reanalysis: The real-time modeling during AOSN-II was reviewed and assessed (Haley et al, 2009). Figure 2 shows the daily evolution of the surface temperature during the first upwelling event of the MB06 experiment. In the first half of this upwelling event, waters are advected southwards across the mouth of Monterey Bay while in the second half, waters are advected offshore.

Ocean Flux and Term Balances: The average balances for this first upwelling event are shown in Figures 3 and 4. In Fig. 3, the volume-averaged rate of change of temperature is plotted as a function of time, at 3 hour intervals. The bulk cooling of the test volume occurs during the first half of the upwelling event (31 Jul - 2 Aug). A second feature highlighted by this plot is the strong tidal signal in the volume average rate of change of temperature. Figure 4 shows the temperature fluxes through the volume boundaries averaged over the first upwelling event (00Z Jul 31 - 00Z Aug 4, 2006). On average, the dominant cooling energy source is advection through the lateral boundaries. The source of the upwelled waters can be seen as an inflow through the western boundary, on the shelf, between 25-125m, centered around 122.55W. The forecasts were found to have skill out to 2 days, especially near the surface. The reanalysis following the experiment was found to improve both the long-term stability of the simulations and the quantitative skill (especially in the main thermocline where the simulation RMS temperature errors were 1^oC less than persistence RMS errors, see Haley et al., 2009).

New Nested Schemes for Free-Surface Primitive Equation Modeling: The new nesting scheme strengthened the feed-back from the fine domain to the coarse domain, treating the solutions in the two domains implicitly in time. The effects of this new scheme are illustrated in figures 5 and 6 in the idealized set-up. Figure 5 shows the differences between the barotropic velocities estimated in the coarse and fine domains of the old and new nested simulations. In the top row, the differences are for the nested run using the original nesting algorithm. Here, large scale patterns are seen in the difference fields, growing to around 35 cm/s in 18 days. In the bottom row, the differences are for the nested run using the new scheme. Here the differences have a smaller scale and are around 3 cm/s after 18 days (down from a peak 7cm/s in the initial conditions). Figure 6 compares the total barotropic velocities from the coarse and fine domains at day 18: both use the new scheme and solutions are plotted in the fine domain. Comparing these total fields with the 18 day differences for the revised algorithm (Fig. 5, bottom row), we see that the increased resolution of the fine domain leads to differences in secondary jets that develops to the north and south of the main jet. These are two "frontal" regions where we would naturally expect larger impacts from higher resolution.

Tidal modeling: The simulation of diurnal tidal constituents (K1, O1, P1, etc) was improved by imposing mixed OBCs. The Dirichlet boundary conditions were relaxed to an absorbing (sponge-like) condition on the northern boundary which eliminated the wave-like adjustments to potentially inconsistent Dirichlet OBCs near the boundaries. The improved tidal simulations were found to be in good agreement with the ADCP depth-averaged data (Figure 7).

IMPACT/APPLICATIONS

This research will contribute to coastal physical oceanography in general and upwelling dynamics in particular. This will increase capabilities of navy operations in these regions, especially the surveillance of transit routes, safety of man-based activities, management of autonomous vehicles, and overall tactical and strategic decision making under uncertainties in sensitive areas.

TRANSITIONS

Interactions and coordination are ongoing with co-PIs and with NRL collaborators of this MURI.

RELATED PROJECTS

Collaborations occur under the ONR grant “Physical and Interdisciplinary Regional Ocean Dynamics and Modeling Systems” (N00014-08-1-1097).

PUBLICATIONS

Haley, P.J. Jr., P.F.J. Lermusiaux, A.R. Robinson, W.G. Leslie, O. Logutov, et al., 2009. Forecasting and Reanalysis in the Monterey Bay/California Current Region for the Autonomous Ocean Sampling Network-II Experiment, Special issue on AOSN-II, Deep Sea Research Part II: Topical Studies in Oceanography, 56, 127-148, ISSN 0967-0645, doi:10.1016/j.dsr2.2008.08.010. [Published, refereed]

Logutov, O.G., 2008. A multigrid methodology for assimilation of measurements into regional tidal models, Ocean Dynamics, 58, 441-460, doi:10.1007/s10236-008-0163-4. [Published, refereed]

Logutov, O.G. and P.F.J. Lermusiaux, 2008. Inverse Barotropic Tidal Estimation for Regional Ocean Applications, Ocean Modelling, 25, 17-34. doi:10.1016/j.ocemod.2008.06.004. [Published, refereed]

Ramp, S.R., R. E. Davis, N. E. Leonard, I. Shulman, Y. Chao, A. R. Robinson, J. Marsden, P.F.J. Lermusiaux, D. Fratantoni, J. D. Paduan, F. Chavez, F. L. Bahr, S. Liang, W. Leslie, and Z. Li, 2009. Preparing to Predict: The Second Autonomous Ocean Sampling Network (AOSN-II) Experiment in the Monterey Bay. Special issue on AOSN-II, Deep Sea Research, Part II. [Published, refereed].

FIGURES

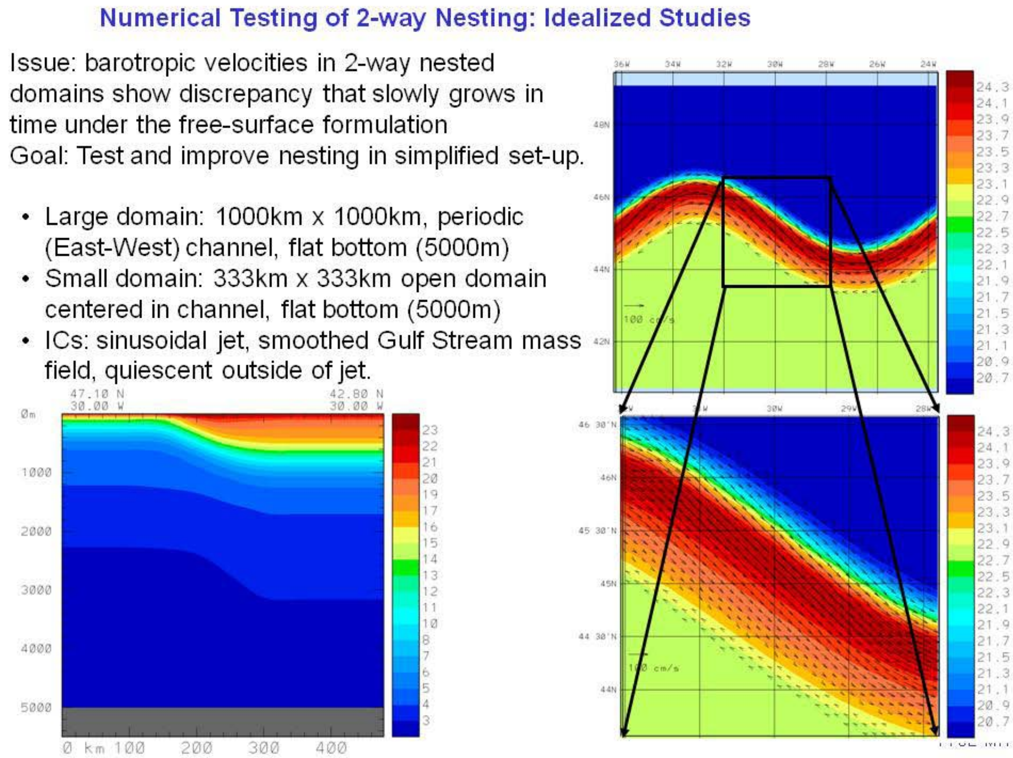


Figure 1. Idealized test case for testing 2-way nesting algorithms.

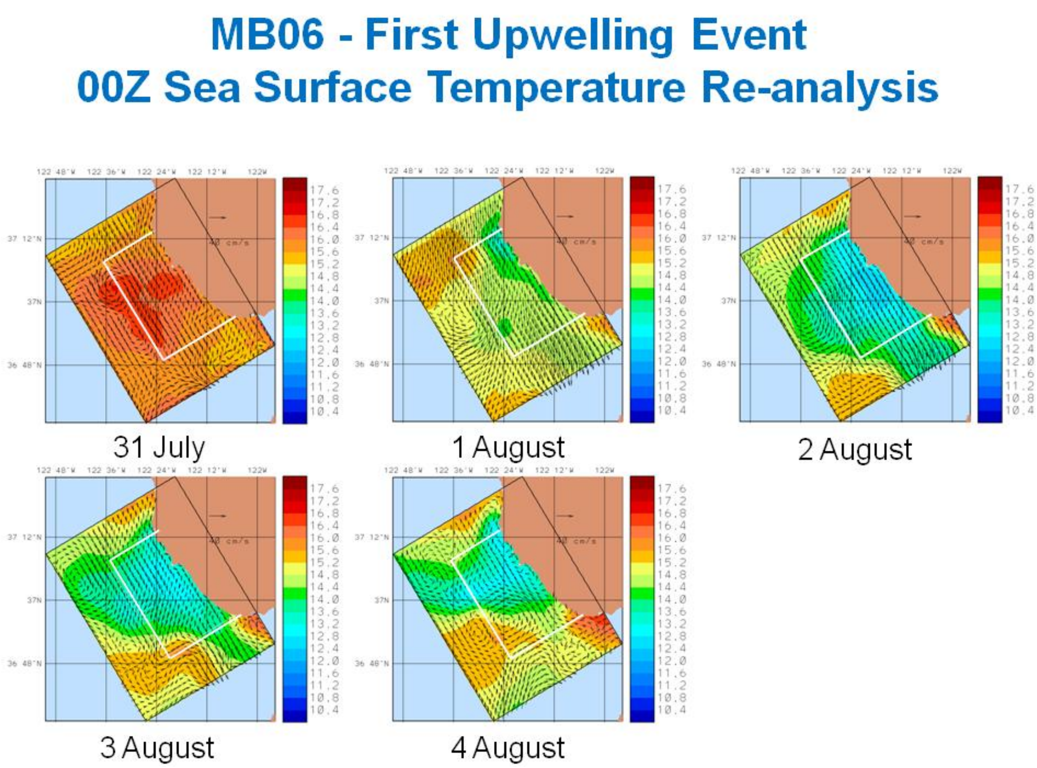
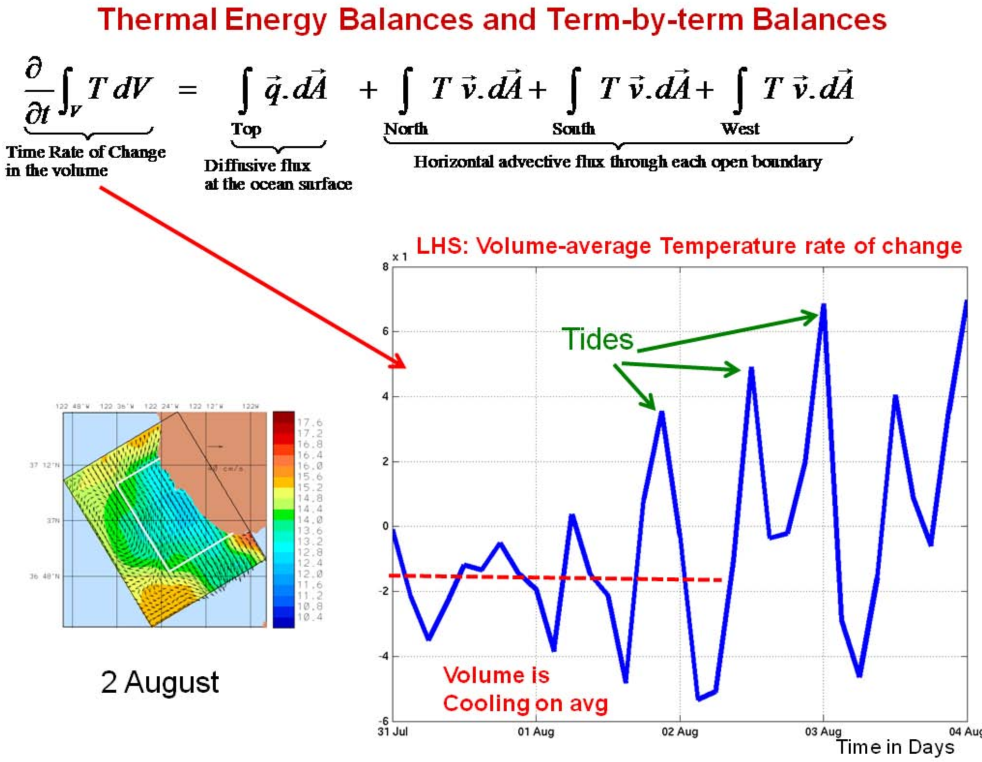


Figure 2. Reanalysis surface temperature during the first upwelling event of MB06 experiment.



$$\frac{\partial}{\partial t}\int_V T\,dV = \int_{Top} \vec{q}.d\vec{A} + \int_{North} T\,\vec{v}.d\vec{A} + \int_{South} T\,\vec{v}.d\vec{A} + \int_{West} T\,\vec{v}.d\vec{A}$$

Figure 3. Volume average time rate of change of temperature as a function of time during the first upwelling event of MB06.

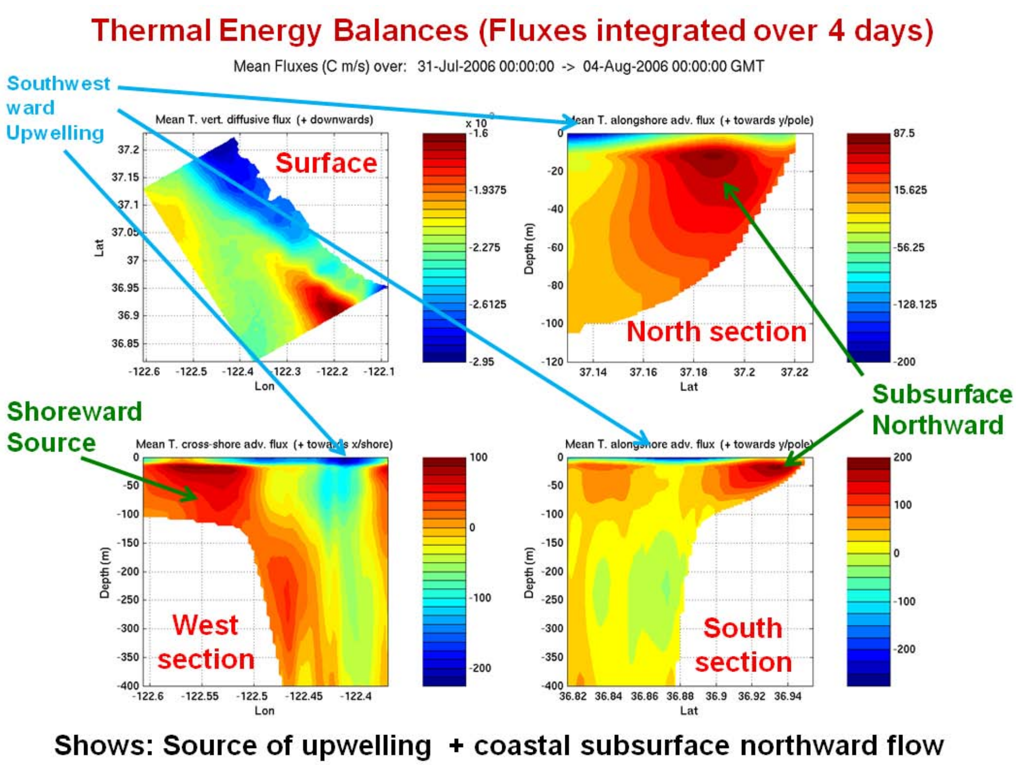


Figure 4. Advective and diffusive temperature fluxes through the boundaries of the control volume, averaged over the 4 days of the first upwelling event of MB06.

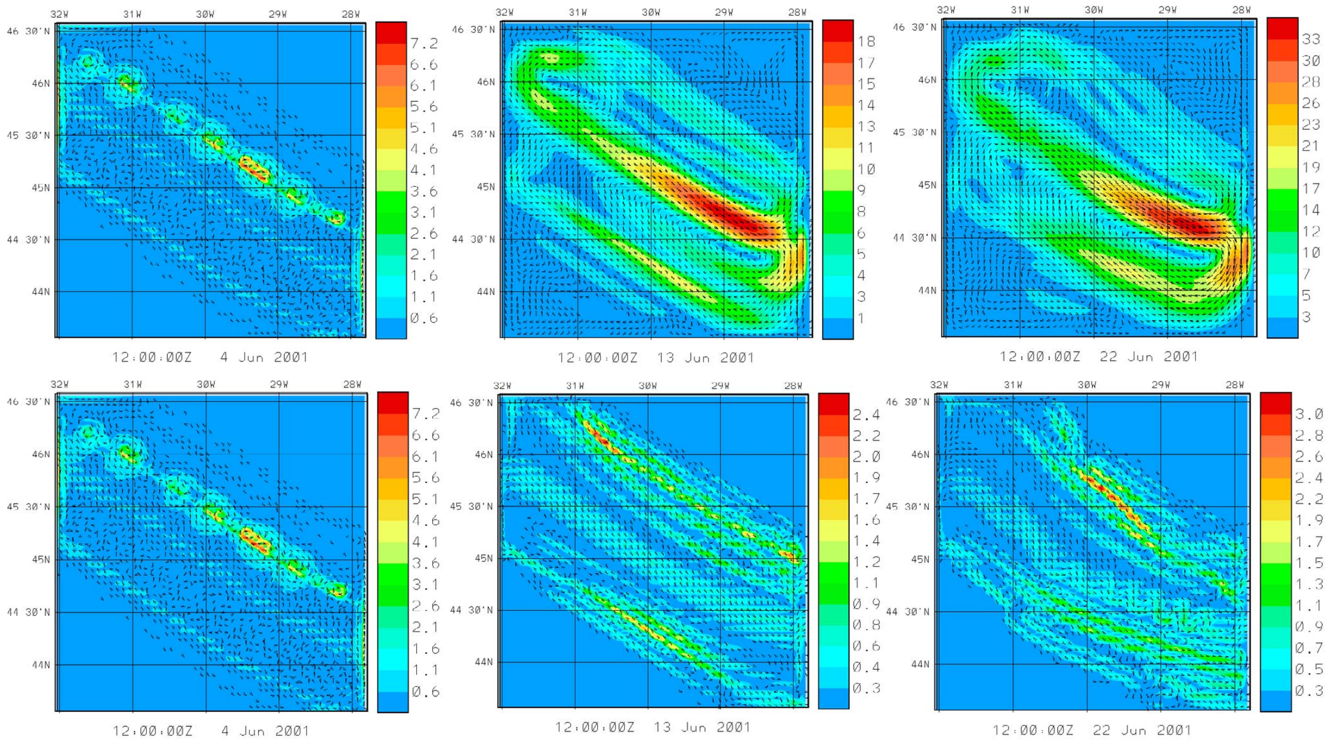


Figure 5. Differences plots between the barotropic velocity estimates produced in the coarse and fine domains of nested idealized simulations (IC, 9days and 18days). Top row: differences from nested pair using original algorithm. Bottom row: differences from nested pair using revised algorithm.

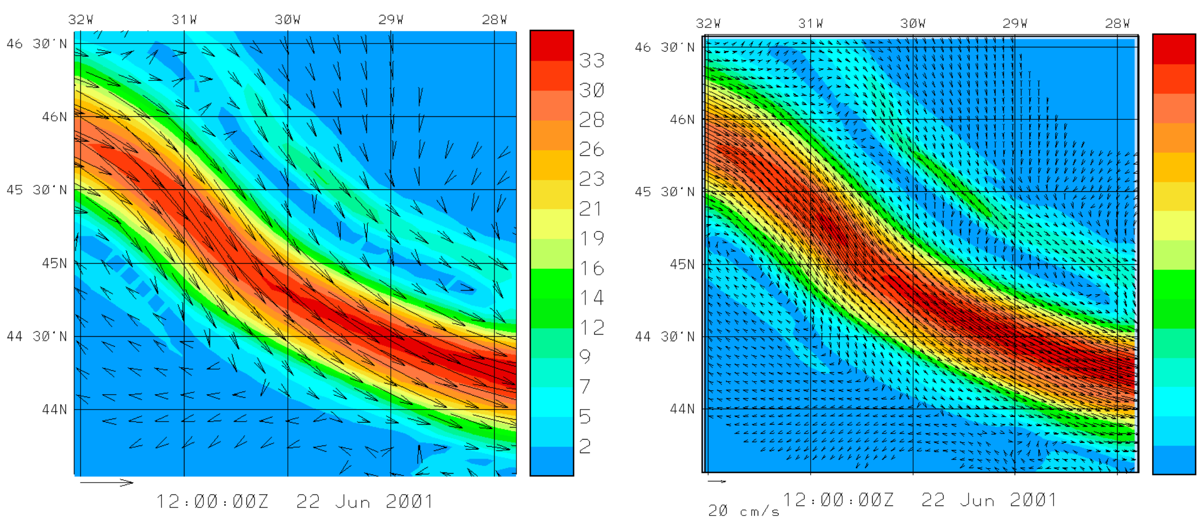


Figure 6. Barotropic velocity estimates at 18 days in a 2 way nested simulation using revised algorithm. Left: coarse domain estimate plotted in the fine domain. Right: fine domain estimate. Comparing to Fig 5 (bottom row), the increased resolution leads to differences in the transition regions in the main and secondary jet, where the resolution matters most.

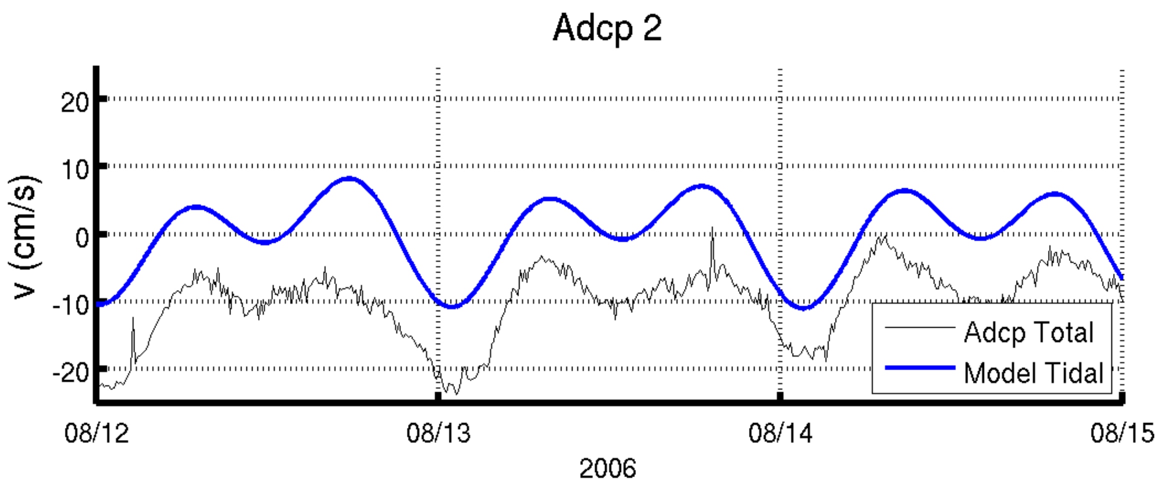


Figure 7. Comparison of observed (thin line) and modeled (thick line) velocities.